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Magnetic analysis of the splice fields in HFDA magnets

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This note summarizes the end field analysis for the HFDA magnet series including the HFDA-03A and HFDM mirror configurations and the next dipole model HFDA05. The simulations were performed using OPERA 3D code.

HFDA-03A mirror magnet

This magnet utilized one of the HFDA03 half-coils. The 2D magnetic analysis is described in technical note TD-02-045. The Nb_3Sn leads in this coil are displaced from the midplane in order to simplify their splicing with NbTi leads. Figure 1 shows the lead end view of the OPERA 3D model with the flux density diagrams and Figure 2 shows the field on the conductor surfaces in YZ cross-section. The peak field point belongs to the inner pole cable in the central part of the magnet. Field distribution along the lead cables of the inner and outer layers is presented in Figure 3. The maximum field in the old splices is 0.4 T and in the new splices is 2.9 T at 6 kA current.

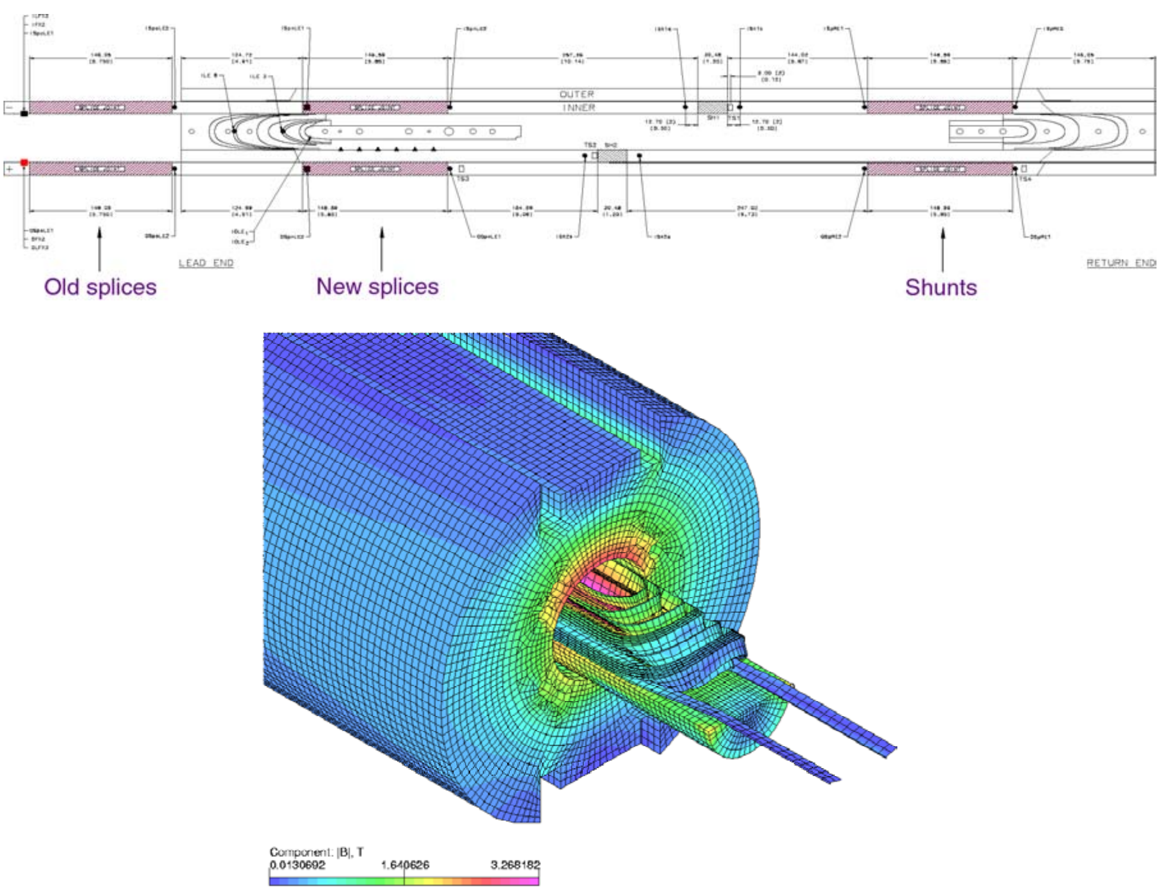

Figure 1. Splice location (top) and the lead end view of HFDA-03A model at 6 kA.

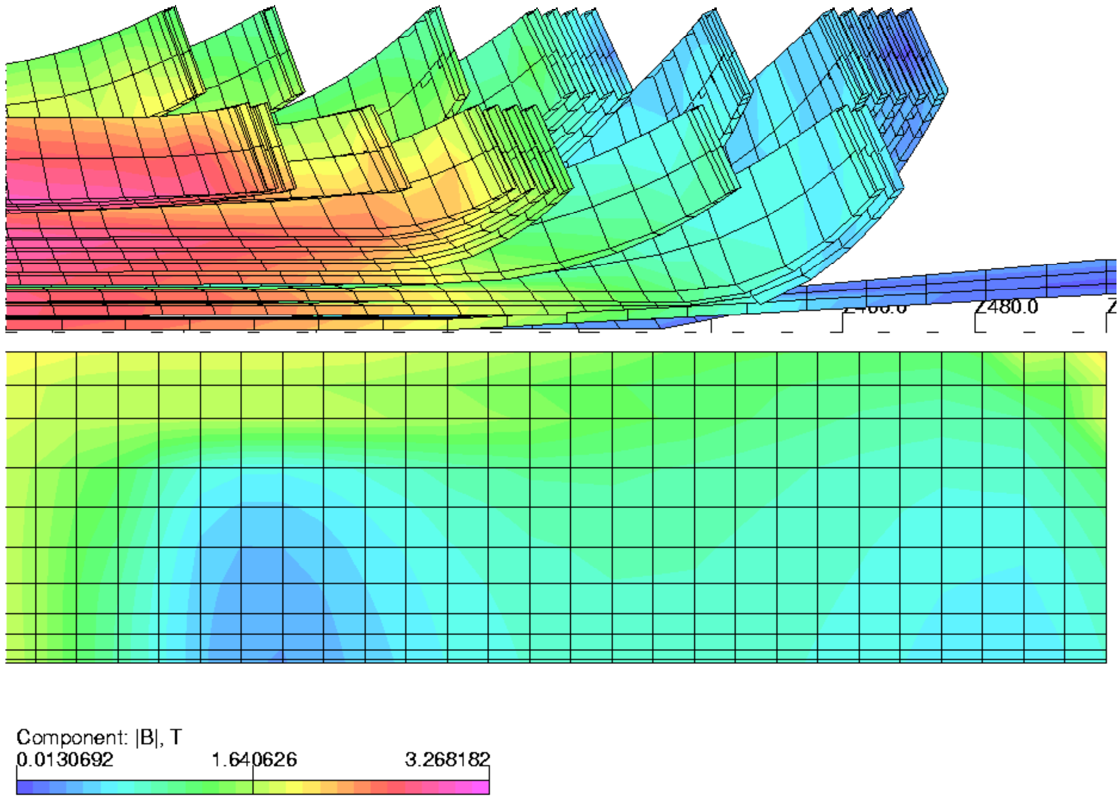

Figure 2. Field in YZ coil cross-section at 6kA.

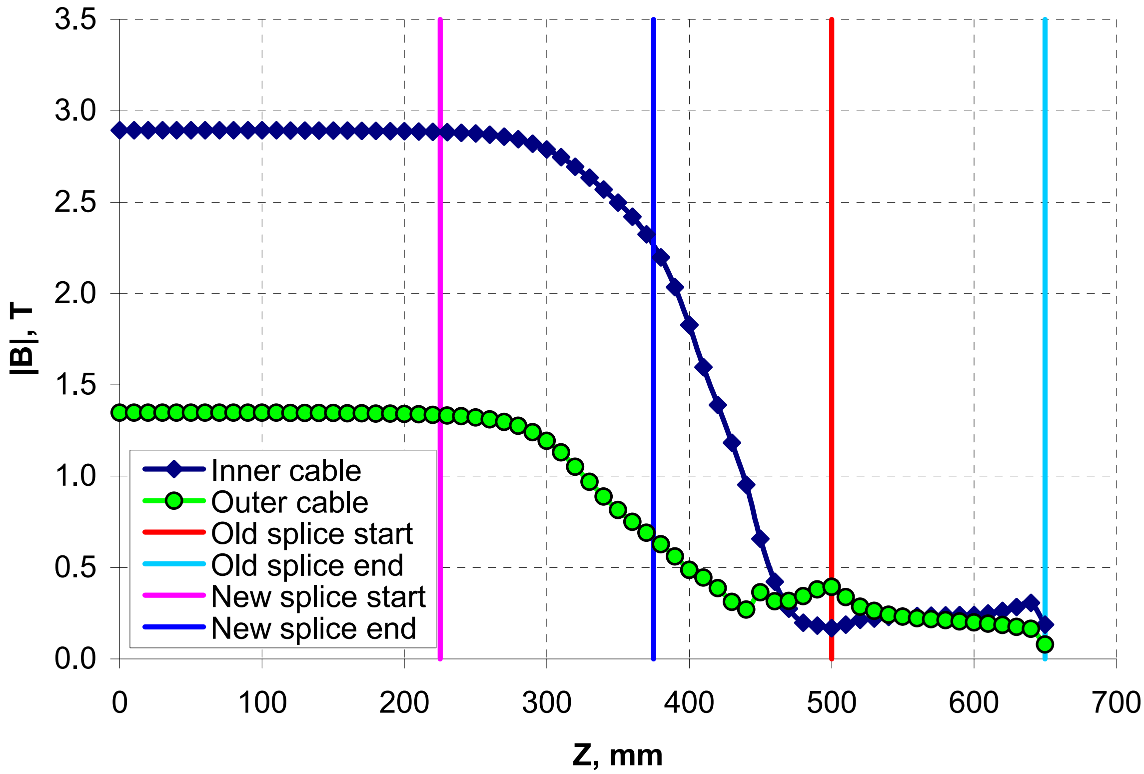

Figure 3. Peak field distribution along the lead cables at 6 kA.

HFDM mirror magnet

These mirror configurations will be used to test new half-coils with modified (HFDA04 type) lead design. The splice cables are straight all the way down to the NbTi leads and mechanically supported by the end shoes. This splice design reduces the possibility of the lead damage during splicing. Another difference with respect to the previous mirror configuration is the iron yoke orientation with the horizontal split parallel to the coil midplane. In addition, in this design the iron yoke extends all over the coil length (shoe to shoe) and the size of the iron half-cylinders was increase to eliminate the Al spacers between mirror and iron yoke.

Figure 4 shows the magnet cross-section with the field diagram at 20 kA current. Figures 5-8 present the quench field, load lines, transfer function, inductance and stored energy for this design and other possible modifications. The cases with and without the Al spacer show essentially the same quench field and other parameters. However, in the case without iron yoke, the quench field is 6.5 % less at the same current.

The OPERA 3D model used in the splice field analysis is shown in Figure 9. The YZ cross-section of the coil lead end is presented in Figure 10. Since the iron yoke extends over the coil ends, the peak field point belongs to the inner pole cable in the return end. However, the end peak field exceeds the body peak field only by 0.5 %, which virtually does not affect the magnet quench performance.

The peak field distribution along the leads at 20 kA current and the NbTi cable critical field are shown in Figure 11. Since in the new coil end design the splices were moved inside the coil, the maximum field in the splice at the same current is by a factor of 3 larger than in the previous coil design. Nevertheless, there is 280 % quench margin at the beginning of the NbTi cable due to zero transport current at this point. Thus, the NbTi cables should not cause any problems in the present coil design. However, moving the splice just by 40 mm outwards would reduce the maximum field in the splices by a factor of 2.3.

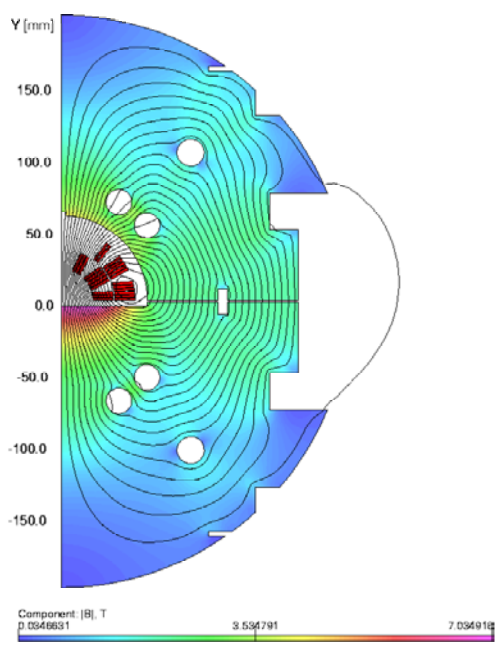

Figure 4. HFDA-03B magnet cross-section.

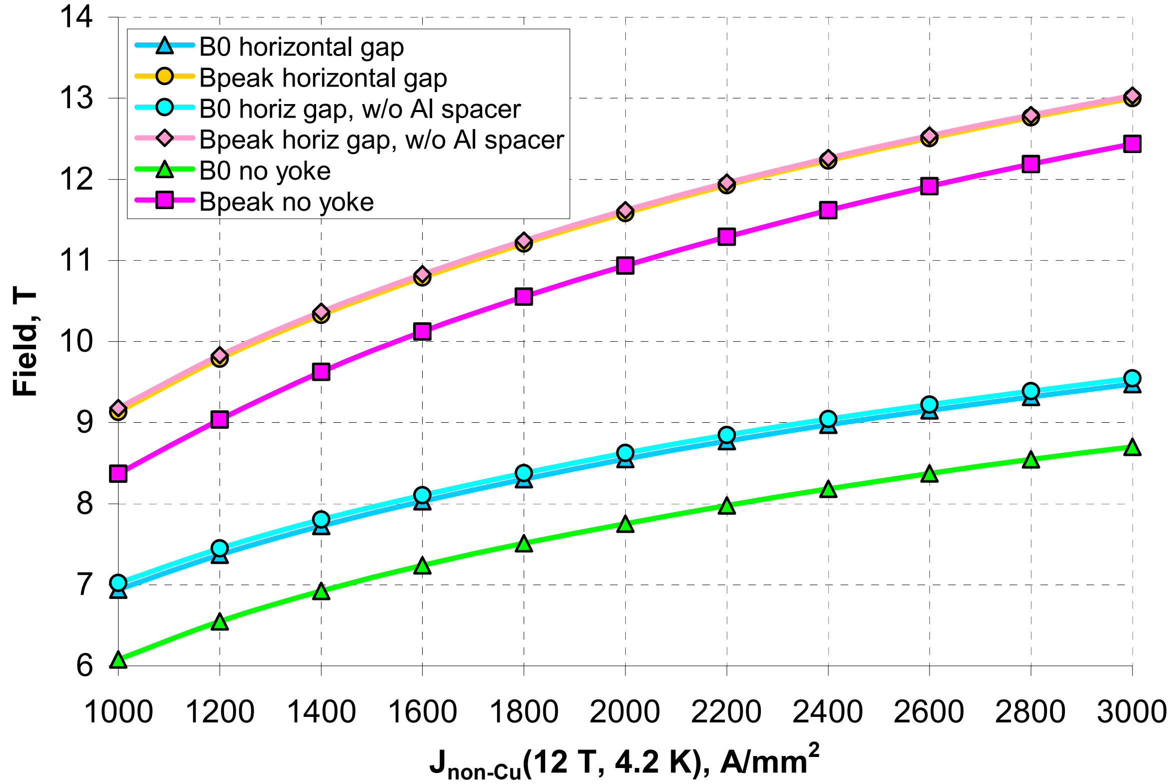

Figure 5. Quench fields as functions of the short sample limit.

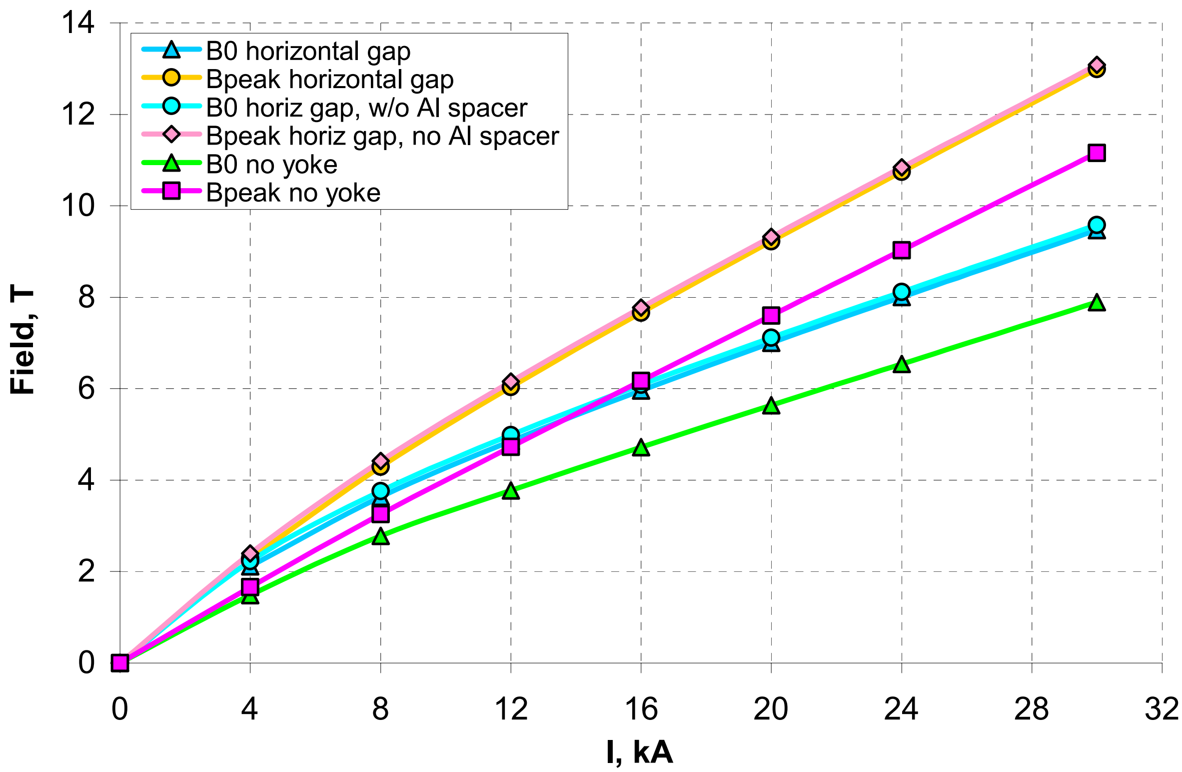

Figure 6. Magnet load lines.

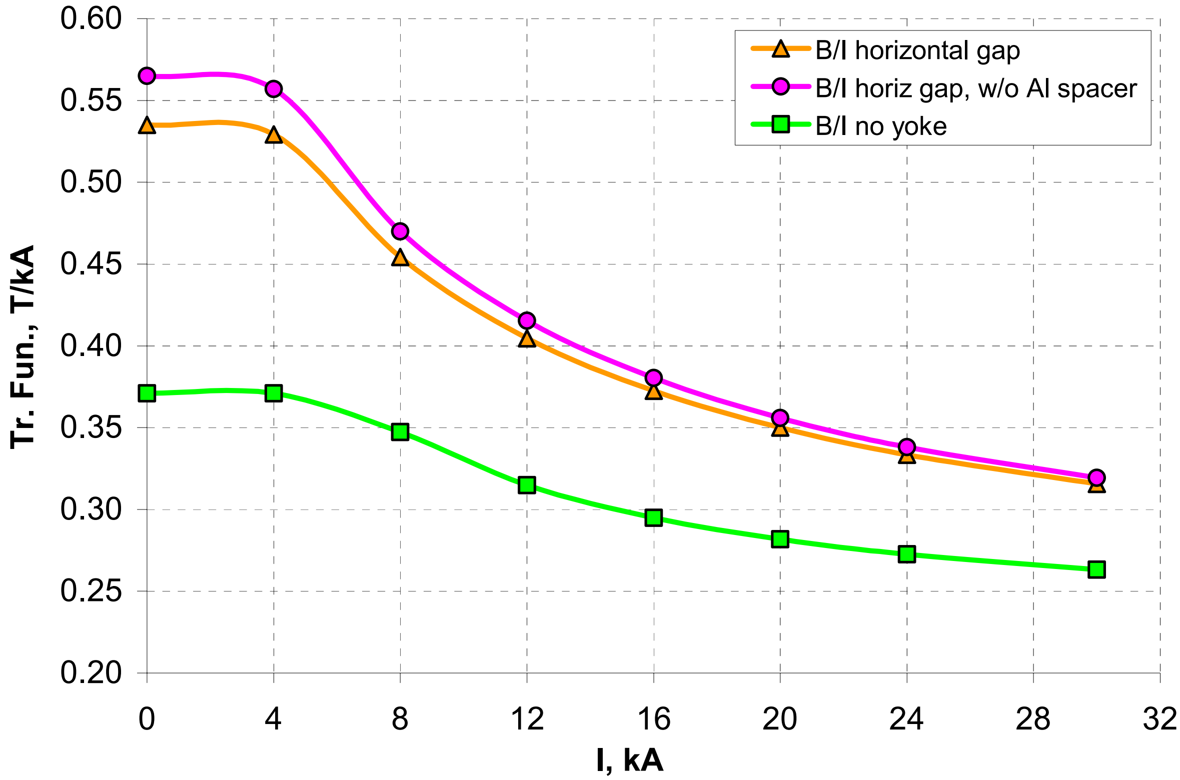

Figure 7. Transfer function vs. magnet current.

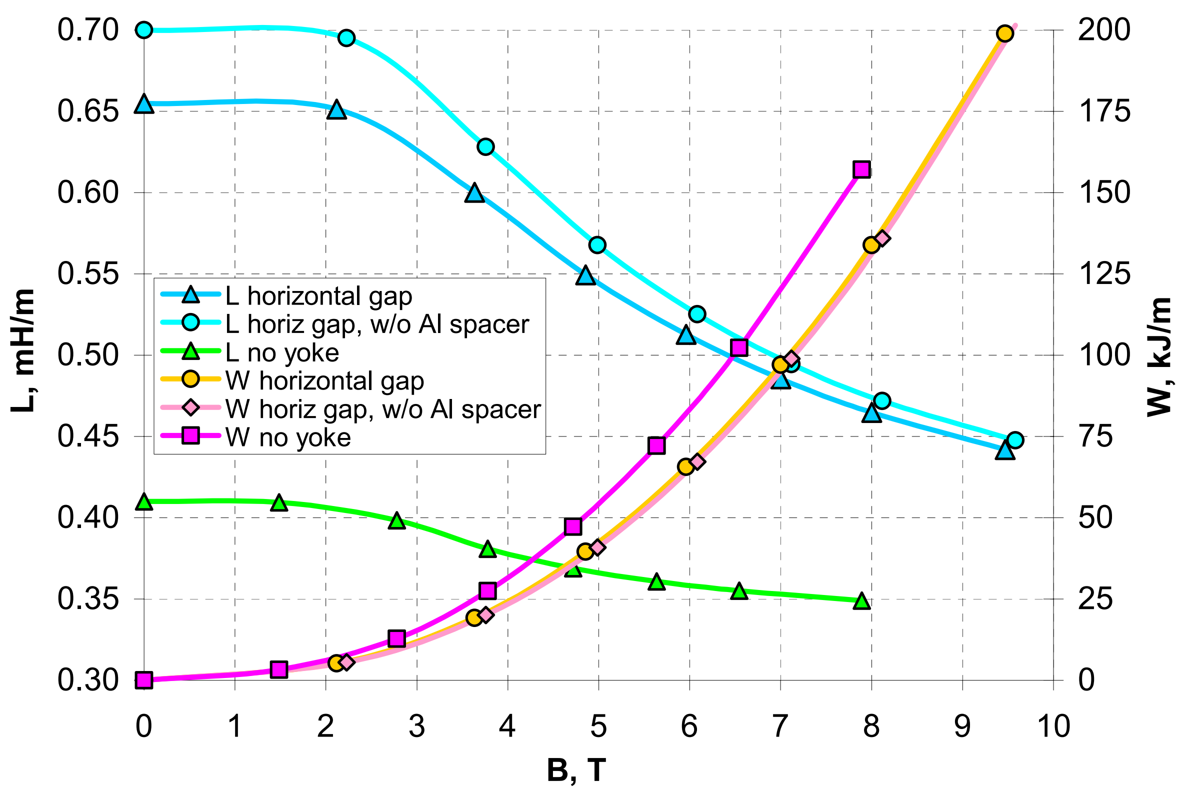

Figure 8. Inductance and stored energy.

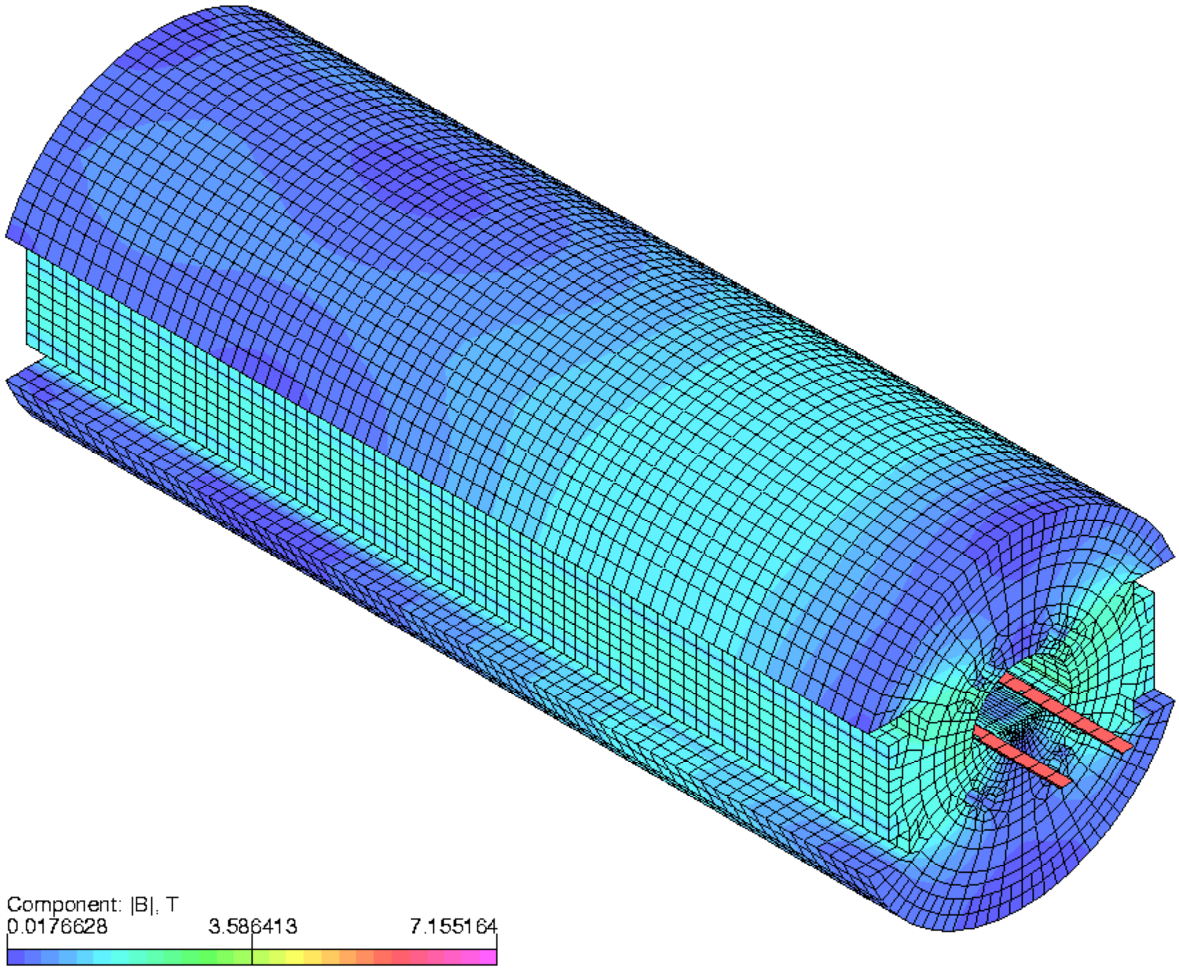

Figure 9. Lead end view of HFDA-03B model at 20 kA.

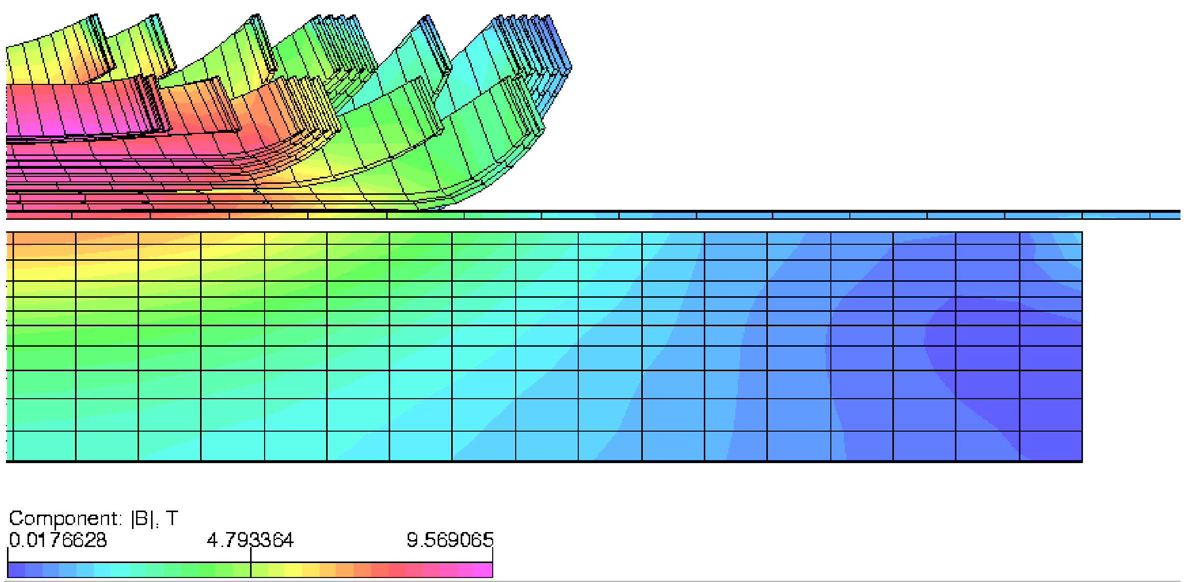

Figure 10. Field in YZ coil cross-section at 20kA.

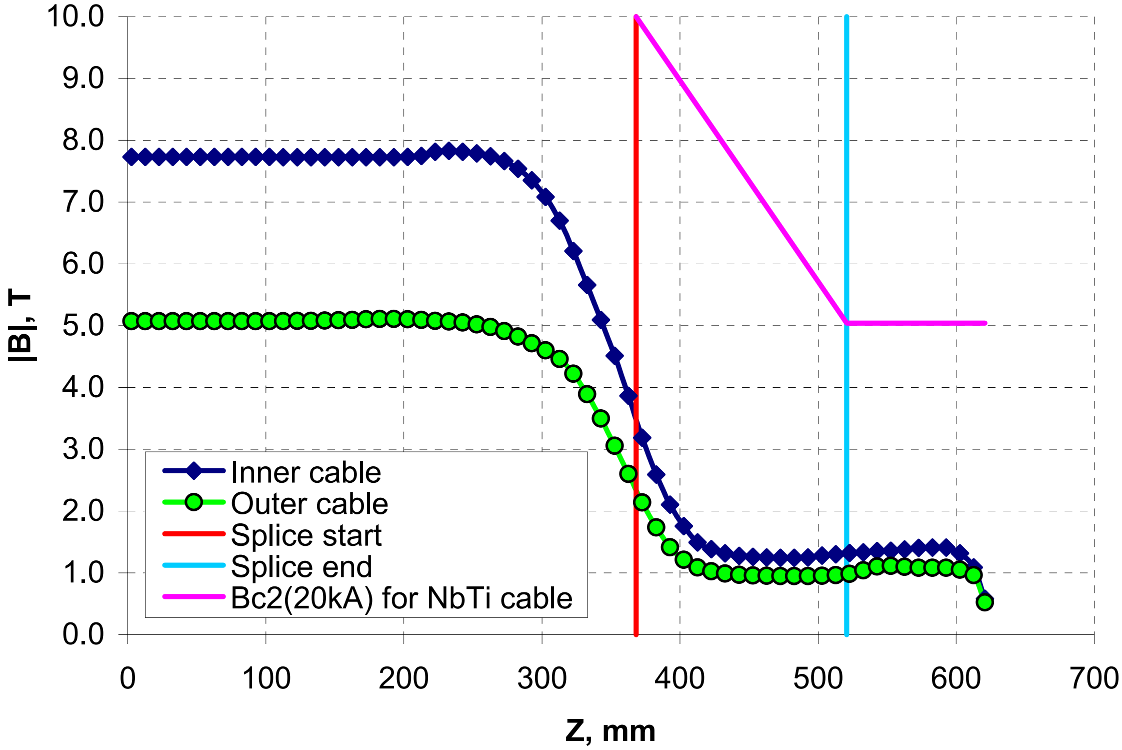

Figure 11. Peak field distribution along the lead cables at 20 kA.

Dipole model HFDA-05

The next dipole magnet of HFDA series will contain two coils of the same geometry as it was used in HFDA-04. However, the iron yoke extends over the coil length, similarly to HFDM mirror magnet in order to avoid interfaces of two materials with different thermal contraction in the coil area. Apart from that, there are no essential changes with respect to HFDA-04 magnet in terms of the magnetic design. Thus, the 2D analysis presented in the technical note TD-00-036 should be used to determine the magnet parameters.

Figure 12 presents the lead end view of the OPERA 3D model and Figure 13 shows the field diagram in the coil lead end at 20 kA. The peak field in the coil ends is 1% higher than in the straight section due to extension of the iron yoke over the coil ends.

The peak field distribution in the coil leads is shown in Figure 14 along with the critical field of the NbTi cable at 20 kA. The peak field in the splice is a little higher than in HFDM mirror magnet, although the margin to quench of the NbTi cable is as high as 250%.

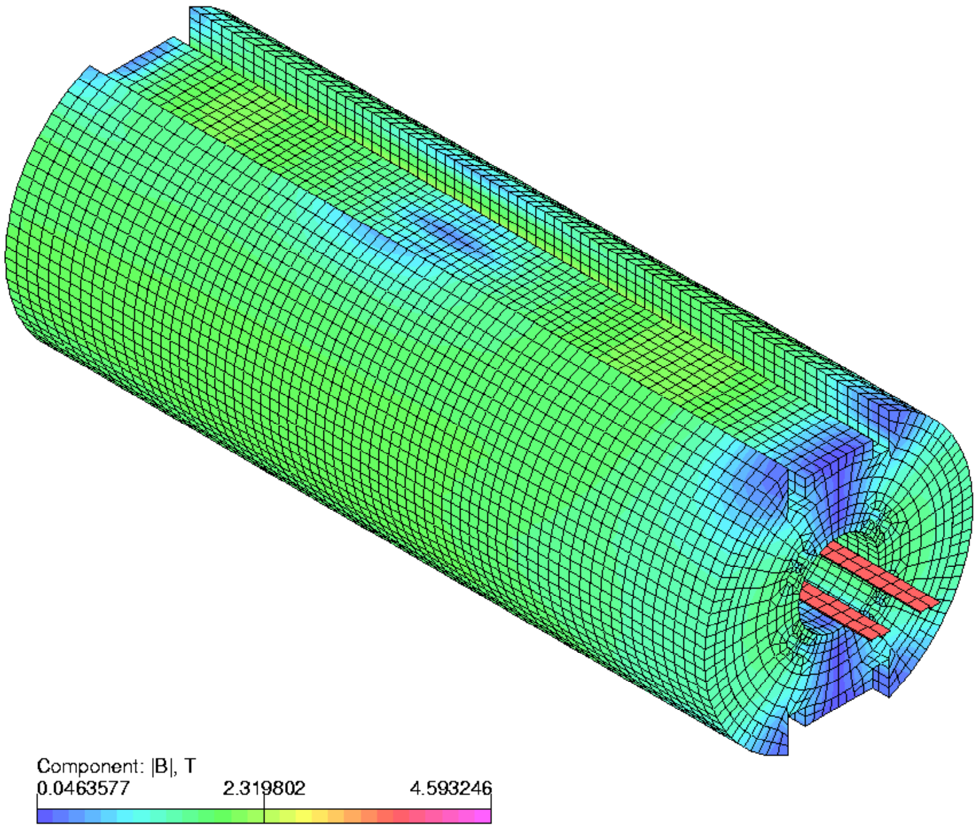

Figure 12. Lead end view of HFDA-05 model at 20 kA.

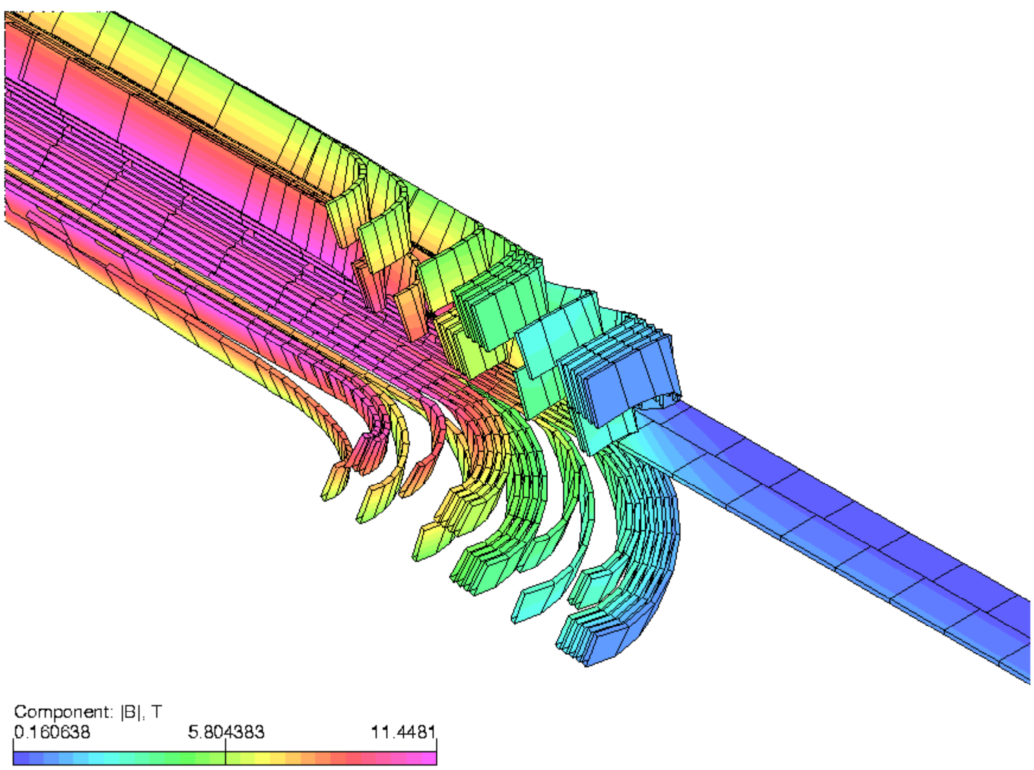

Figure 13. YZ coil cross-section with the field diagram at 20 kA.

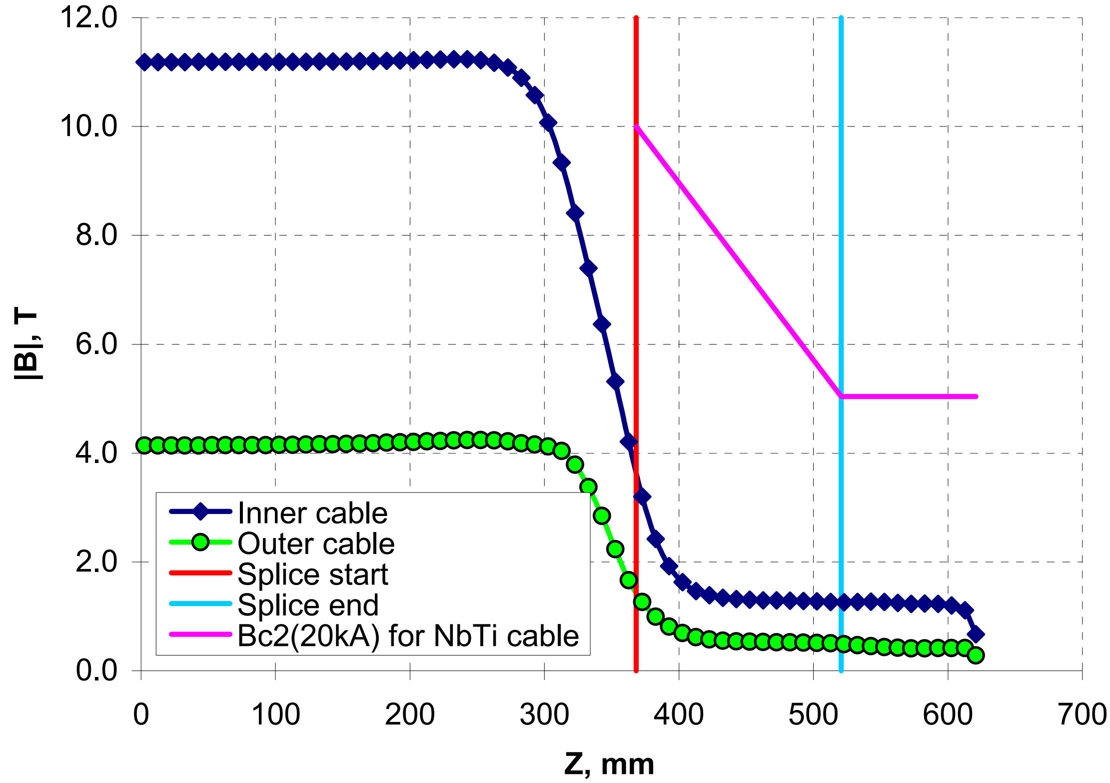

Figure 14. Peak field distribution along the lead cables at 20 kA.